Satellite Mapping of Great Lakes Ice Cover

George A. Leshkevich

NOAA/Great Lakes Environmental Research Laboratory
Ann Arbor, Michigan 48105 USA

Much of the satellite ice interpretation algorithm development in the Great Lakes region began during the Extension to the Navigation Season Demonstration Study conducted during the 1970's. However, many of the early studies were done by visual interpretation of satellite and other remotely sensed data. Starting in the mid-1970's, a series of studies including field studies and computer digital image processing, explored techniques and algorithms to classify and map freshwater ice cover using Landsat, NOAA/AVHRR, and ERS-1 SAR data. The goal of much of this work is to develop an automated or semi-automated method to classify and map Great Lakes ice cover using satellite digital imagery.

Introduction

In his recommendations for Great Lakes ice research, Marshall (1966) concludes that "studies are needed to classify Great Lakes ice types, their distribution and drift during the winter, and the subtle changes in albedo and imagery which mark the gradual disintegration of the ice and the imminent breakup." Early investigations by various researchers were conducted to classify and categorize ice types and features (Chase,1972; Bryan, 1975), to map ice distribution (McMillan and Forsyth, 1976; Leshkevich, 1976), and to monitor and attempt to forecast ice movement with remotely sensed data (Strong, 1973; McGinnis and Schneider, 1978; Rumer et al.,1979; Schneider et al., 1981). Most of the early research on Great Lakes ice cover was done by visual interpretation of satellite and other remotely sensed data (Rondy, 1971; Schertler et al., 1975; Wartha, 1977). Because of the size and extent of the Great Lakes and the variety of ice types found there, the timely and objective qualities inherent in computer processing of satellite data make it well suited for such studies.

Northern Green Bay

Northern Green Bay ice cover on February 13, 1975 was analyzed from Landsat-1 digital data using computer image processing techniques. The purpose of this study was to investigate whether Landsat digital data can be used for objective classification of various types of Great Lakes ice cover. The major objectives were to determine if new ice (thin ice) could be differentiated from water, if ice could be differentiated from cloud cover, and if various ice types could be classified using a maximum-likelihood procedure. Secondary objectives included determining the percent coverage of each ice type and calculating the total percentage of water surface covered by ice.

Training sets, consisting of selected areas in the Landsat scene that represented various ice types, were entered based on the tone, texture, and location of the ice within the bay. The classification algorithm used in the analysis consisted of a modified maximum likelihood procedure using the multivariate Gaussian probability density function. It was found that seven ice types could be differentiated in the ice cover, that new (thin) ice could be distinguished from water, and that ice could be distinguished from relatively thin cloud cover (Leshkevich, 1981). However, could this analysis be duplicated in another scene, and could it be automated?

Ice Albedos as Training Sets

In a second study, the purpose was to determine whether previously gathered reflectance values for various types of freshwater ice could be converted to digital numbers and used as training sets to classify Great Lakes ice cover using Landsat digital data. A method was developed and used to convert ground-measured freshwater ice albedos to Landsat-1 digital numbers indirectly corrected for atmospheric attenuation and path radiance. The method was tested by using the digital numbers as training sets to machine classify Landsat-1 digital ice cover data from a portion of the northern Green Bay scene imaged on Febuary 13, 1975. Results showed that the conversion algorithm produced digital numbers numbers that, when used as training sets, classified approximately 50% of the test area. The results of the classification are a verification of the algorithm and not an absolute classification of ice types in the test area. Differences between the classified test area and a previous machine classification of the Green Bay scene, as well as the percentage of unclassified area caused by lack of data for some surface types, pointed to the need for a more comprehensive, well-documented library of signatures representing Great Lakes ice types (Leshkevich, 1985a).

Airborne Measurements

In an attempt to compile such a library, field measurements of the spectral reflectance of major Great Lakes ice types were made in March, 1984 and again in March, 1985. The instrumentation and measurement technique used were basically the same in both years. Measurements made on March 26 and 27, 1984 were over large areas of surface types on southern Lake Huron including open water, refrozen slush ice, densely consolidated brash, large floes in a black ice matrix, and skim ice, and are described by Leshkevich and Reid (1984). Additional measurements were made on March 20, 1985 on Saginaw Bay (Lake Huron) over open water, old snow, and windrowed, snow-covered ice. The purpose of this study was to obtain airborne measurements (from an altitude of 300 m) of major freshwater ice types and combinations in the 400-1100 nm range for use in satellite interpretation and lakewide ice albedo estimates. The objective was to measure the spectral reflectance of relatively large homogeneous and heterogeneous areas of various freshwater ice types under clear skies.

A programmable band spectral radiometer was used to acquire data. The instrument and cassette data logger were powered by a 12 VDC battery, which allowed for the needed mobility. Using a three sector chopper wheel and a detector array, the instrument was capable of measuring radiance, irradiance, and dark current in about 3 seconds, which made measurement from a helicopter possible. Three measurements were made over each surface type and averaged. Simultaneous radiance and irradiance measurements were also made at the surface over a spray-painted barium sulfate reference panel and over snow and water. After determining the spectral reflectance of the snow and water, an algorithm was applied to calculate the spectral reflectance of the ice types measured from 300 m, corrected for atmospheric attenuation and path radiance (Leshkevich, 1985b).

However, Kimes and Kirchner (1982) and others noted that the assumption of a Lambertian reference panel was not necessarily valid. The non-Lambertian behavior of a reference panel can cause considerable error when its radiance data is used in the calculation of reflectance factors or in the characterization of irradiance conditions. Goniometric measurements of the spray-painted barium sulfate reference panel were made to determine its Lambertian characteristics in the visible and near-infrared (400-1100 nm) range for zenith angles from 0 to 80 degrees. Errors in Lambertian response varied with zenith angle and wavelength and ranged from 0 to 52% in the visible and .03 to 30% in the near-infrared (Leshkevich, 1988a). A technique to correct calculated reflectance factors of field targets collected under clear sky conditions for the non-Lambertian response of the spray-painted barium sulfate reference panel was used to correct the airborne reflectance measurements made over Saginaw Bay (Leshkevich, 1988b).

Bi-directional Reflectance

Although the NOAA series of satellites with high temporal and broad spacial coverage are well suited for Great Lakes ice monitoring , the large scan angles inherent in AVHRR data may hinder interpretation based on nadir-looking measurements. Ott et al. (1984) demonstrated the value of angular (directional) reflectance data or "angular signatures" in the interpretation of aircraft and satellite sensor data. To improve the interpretation of surface cryospheric albedo from satellite sensor data, diurnal measurements of the spectral bi-directional reflectance of a commonly-found fresh-water ice type were made, from which hemispherical reflectance can also be derived. The purpose of this study was to document its clear-sky, bi-directional reflectance characteristics in the visible (650-670 nm) and near-infrared (810-840 nm) region, assess the diurnal nature of the reflectance, and quantify the surface anisotropy. Bi-directional reflectances of the re-frozen slush ice (white ice) measured show a spectral dependence and changed significantly with solar zenith angle. Considerable variation occured at each view angle and among view angles throughout the day. Although diurnal reflectance patterns were similar in both bands, magnitudes varied greatly, being highest in the visible and lowest in the near-infrared region. With the exception of peak saturated (specular) values in the forward scatter direction, bi-directional reflectance was generally highest in the morning when the surface and the illumination were most diffuse in character (Leshkevich et al., 1990).

A database containing such measurements, acquired for different ice and snow surface types, could improve interpretation of these different surface types using satellite sensor data and improve the estimation of hemispheric reflectance from satellite observations of the Earth-atmosphere system (Kimes et al., 1987), a parameter needed for climate and radiation budget models for the shortwave spectrum.

GLERL Contribution No. 981

References

Bryan, M.L. (1975), A comparison of ERTS-1 and SLAR data for the study of surface water resources, Final Report, ERIM No. 193300-59-F, prepared for the National Aeronautics and Space Administration by the Environmental Research Institute of Michigan, Ann Arbor, MI under Contract No. NAS5-21783, 104 pp.

Chase, P.E. (1972), Guide to ice interpretation: Satellite imagery and drift ice, Final Report prepared for the U.S. Department of Commerce by The Bendix Corp, Aerospace Systems Division, Ann Arbor, MI, under Contract No. 2-35372, 24 pp.

Kimes, D.S., and Kirchner, J.A. (1982), Irradiance measurement errors due to the assumption of a Lambertian reference panel, *Remote Sens. Environ.,* 12:141-149.

Kimes, D.S., Sellers, P.J., and Diner, D.J. (1987), Extraction of spectral hemispherical reflectance (albedo) of surfaces from nadir and directional reflectance data, *Int. J. Remote Sensing,* 8(12), 1727-1746.

Leshkevich, G.A. (1976), Great Lakes ice cover, winter 1974-75, NOAA Technical Report ERL 370-GLERL 11, National Technical Information Service, Springfield, VA 22161, 42 pp.

Leshkevich, G.A. (1981), Categorization of northern Green Bay ice cover using Landsat-1 digital data--a case study, NOAA Technical Memorandum ERL GLERL-33, National Technical Information Service, Springfield, VA 22161, 19 pp.

Leshkevich, G.A. and Reid, N.J. (1984), Airborne measurements of freshwater ice albedos, Proceedings of the Eighteenth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan , Ann Arbor, MI, pp.1677-1687.

Leshkevich, G.A. (1985a), Machine classification of freshwater ice types from Landsat-1 digital data using ice albedos as training sets, *Remote Sens. Environ.,* 17(3), 251-263.

Leshkevich, G.A. (1985b), Airborne measurements of the spectral reflectance of freshwater ice, Proceedings of the Third International Colloquium on Spectral Signatures of Objects in Remote Sensing, ESA SP-247, pp. 245-248.

Leshkevich, G.A. (1988a), Goniometric measurements of a spray-painted barium sulfate reference panel, *Remote Sens. Environ.,* 24:287-296.

Leshkevich, G.A. (1988b), Non-Lambertian reference panel effect on spectral reflectance measurements of freshwater ice, *Int. J. Remote Sensing,* 9(4), 825-832.

Leshkevich, G.A., Deering, D.W., Eck, T.F., and Ahmad, S.P. (1990), Diurnal patterns of the bi-directional reflectance of fresh-water ice, *Annals of Glaciology* 14:153-157.

Marshall, E.W. (1966), Air photo interpretation of Great Lakes ice features, Great Lakes Research Division, Special Report No. 25, University of Michigan, Ann Arbor, MI, p. 89.

McMillan, M.C., and Forsyth, D.G. (1976), Satellite images of Lake Erie ice, January-March 1975, NOAA Technical Memorandum NESS-80, National Technical Information Service, Springfield, VA 22161, 15 pp.

McGinnis, D.F., and Schneider, S.R. (1978), Monitoring river ice breakup from space, *Photogramm. Eng. Remote Sens.* 44(1):57-68.

Ott, W., Pfeiffer, B., and Quiel, F. (1984), Directional reflectance properties determined by analysis of airborne multispectral scanner data and atmospheric correction, *Remote Sensing Environ.,* 16(1), 47-54.

Rondy, D.R. (1971), Great Lakes ice atlas, NOAA Technical Memorandum NOS LSCR 1, National Technical Information Service, Springfield, VA, 22161, 48 pp.

Rumer, R.R., Crissman, R., and Wake, A. (1979), Ice transport in Great Lakes, Water Resources and Environmental Engineering Research Report No. 79-3 prepared for the Great Lakes Environmental Research Laboratory by the State University of New York at Buffalo, Department of Civil Engineering, and the Center for Cold Regions Engineering, Science and Technology, under Contract No. 03-78-B01-104, 275 pp.

Schertler, R.J., Mueller, R.A., Jirberg, R.J., Cooper, D.W., Heighway, J.E., Homes, A.D., Gedney, R.T., and Mark, H. (1975), Great Lakes all-weather ice information system, NASA Technical Memorandum NASA TM X-71815, National Technical Information Service, Springfield, VA, 22161, 13 pp. and 16 pp. of figures.

Schneider, S.R., McGinnis, D.F., Jr., and Gatlin, J.A. (1981), Use of NOAA/AVHRR visible and near-infrared data for land remote sensing, NOAA Technical Report NESS-84, National Technical Information Service, Springfield, VA 22161, 48 pp.

Strong, A.E. (1973), New sensor on NOAA-2 satellite monitors during the 1972-73 Great Lakes ice season, Remote Sensing and Water Resources Management, Proceedings No. 17, American Water Resources Association, Urbana, IL, pp. 171-178.

Wartha, J.H. (1977), Lake Erie ice--winter 1975-76, NOAA Technical Memorandum NESS-90, National Technical Information Service, Springfield, VA, 22161, 68 pp.

NASA Conference Publication 3318

First Moderate Resolution Imaging Spectroradiometer (MODIS) Snow and Ice Workshop

Edited by
Dorothy K. Hall
NASA Goddard Space Flight Center
Greenbelt, Maryland

Proceedings of a workshop sponsored by the NASA/Goddard Space Flight Center and held at the U.S. Geological Survey in Reston, Virginia and at Goddard Space Flight Center in Greenbelt, Maryland
September 13-14, 1995

National Aeronautics
and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

1995